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UTILITY PATENT APPLICATION TRANSMITTAL
(Large Entity)

(Only for new nonprovisional applications under 37 CFR 1.53(b))

Docket No. YO999-479
Total Pages in this Submission

TO THE ASSISTANT COMMISSIONER FOR PATENTS
Box Patent Application
Washington, D.C. 20231

Transmitted herewith for filing under 35 U.S.C. 111(a) and 37 C.F.R. 1.53(b) is a new utility patent application for an invention entitled:

METHOD AND APPARATUS FOR DYNAMICALLY ADJUSTING RESOURCES ASSIGNED TO PLURALITY OF CUSTOMERS, FOR MEETING SERVICE LEVEL AGREEMENTS (SLAs) WITH MINIMAL RESOURCES, AND ALLOWING COMMON POOLS OF RESOURCES TO BE USED ACROSS PLURAL CUSTOMERS ON A DEMAND BASIS

and invented by:

German Goldszmidt, Jean A. Lorrain, Kiyoshi Maruyama, and Dinesh Chandra Verma

If a CONTINUATION APPLICATION, *check appropriate box and supply the requisite information:*

☐ **Continuation** ☐ **Divisional** ☐ **Continuation-in-part (CIP)** of prior application No.: _____

Which is a:

☐ **Continuation** ☐ **Divisional** ☐ **Continuation-in-part (CIP)** of prior application No.: _____

Which is a:

☐ **Continuation** ☐ **Divisional** ☐ **Continuation-in-part (CIP)** of prior application No.: _____

Enclosed are:

Application Elements

1. ☒ Filing fee as calculated and transmitted as described below
2. ☒ Specification having 27 pages and including the following:
   - a. ☒ Descriptive Title of the Invention
   - b. ☐ Cross References to Related Applications *(if applicable)*
   - c. ☐ Statement Regarding Federally-sponsored Research/Development *(if applicable)*
   - d. ☐ Reference to Microfiche Appendix *(if applicable)*
   - e. ☒ Background of the Invention
   - f. ☒ Brief Summary of the Invention
   - g. ☒ Brief Description of the Drawings *(if drawings filed)*
   - h. ☒ Detailed Description
   - i. ☒ Claim(s) as Classified Below
   - j. ☒ Abstract of the Disclosure

UTILITY PATENT APPLICATION TRANSMITTAL
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Total Pages in this Submission

Application Elements (Continued)

3. ☒ Drawing(s) *(when necessary as prescribed by 35 USC 113)*
   a. ☒ Formal Number of Sheets **11 (Figs. 1-Table 5)**
   b. ☐ Informal Number of Sheets _____

4. ☒ Oath or Declaration
   a. ☒ Newly executed *(original or copy)* ☐ Unexecuted
   b. ☐ Copy from a prior application (37 CFR 1.63(d)) *(for continuation/divisional application only)*
   c. ☒ With Power of Attorney ☐ Without Power of Attorney
   d. ☐ *DELETION OF INVENTOR(S)*
   Signed statement attached deleting inventor(s) named in the prior application, see 37 C.F.R. 1.63(d)(2) and 1.33(b).

5. ☐ Incorporation By Reference *(usable if Box 4b is checked)*
The entire disclosure of the prior application, from which a copy of the oath or declaration is supplied under Box 4b, is considered as being part of the disclosure of the accompanying application and is hereby incorporated by reference therein.

6. ☐ Computer Program in Microfiche *(Appendix)*

7. ☐ Nucleotide and/or Amino Acid Sequence Submission *(if applicable, all must be included)*
   a. ☐ Paper Copy
   b. ☐ Computer Readable Copy *(identical to computer copy)*
   c. ☐ Statement Verifying Identical Paper and Computer Readable Copy

Accompanying Application Parts

8. ☒ Assignment Papers *(cover sheet & document(s))*

9. ☐ 37 CFR 3.73(B) Statement *(when there is an assignee)*

10. ☐ English Translation Document *(if applicable)*

11. ☒ Information Disclosure Statement/PTO-1449 ☒ Copies of IDS Citations

12. ☐ Preliminary Amendment

13. ☒ Acknowledgment postcard

14. ☐ Certificate of Mailing
   ☐ First Class ☐ Express Mail *(Specify Label No.):* _____

UTILITY PATENT APPLICATION TRANSMITTAL
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Docket No. YO999-479
Total Pages in this Submission

Accompanying Application Parts (Continued)

15. ☐ Certified Copy of Priority Document(s) *(if foreign priority is claimed)*

16. ☐ Additional Enclosures *(please identify below):*

Fee Calculation and Transmittal

CLAIMS AS FILED

For	#Filed	#Allowed	#Extra	Rate	Fee
Total Claims	48	- 20 =	28	x $18.00	$504.00
Indep. Claims	6	- 3 =	3	x $78.00	$234.00
Multiple Dependent Claims (check if applicable) ☐					$0.00
				BASIC FEE	$690.00
OTHER FEE *(specify purpose)*		**Assignment Recordation**			$40.00
				TOTAL FILING FEE	$1,468.00

☒ A check in the amount of **$1,468.00** to cover the filing fee is enclosed.

☒ The Commissioner is hereby authorized to charge and credit Deposit Account No. **50-0481** as described below. A duplicate copy of this sheet is enclosed.

- ☐ Charge the amount of as filing fee.
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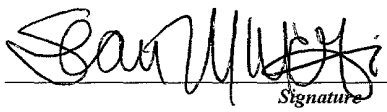
- ☒ Charge any additional filing fees required under 37 C.F.R. 1.16 and 1.17.
- ☐ Charge the issue fee set in 37 C.F.R. 1.18 at the mailing of the Notice of Allowance, pursuant to 37 C.F.R. 1.311(b).



Signature

Dated: **April 28, 2000**

Sean M. McGinn, Esq.
Reg. No.: 34,386

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APPLICATION FOR UNITED STATES LETTERS PATENT

APPLICANTS: German Goldszmidt, Jean A. Lorrain, Kiyoshi Maruyama, and Dinesh Chandra Verma

FOR: METHOD AND APPARATUS FOR DYNAMICALLY ADJUSTING RESOURCES ASSIGNED TO PLURALITY OF CUSTOMERS, FOR MEETING SERVICE LEVEL AGREEMENTS (SLAs) WITH MINIMAL RESOURCES, AND ALLOWING COMMON POOLS OF RESOURCES TO BE USED ACROSS PLURAL CUSTOMERS ON A DEMAND BASIS

DOCKET NO.: YOR999-479

METHOD AND APPARATUS FOR DYNAMICALLY ADJUSTING RESOURCES ASSIGNED TO PLURALITY OF CUSTOMERS, FOR MEETING SERVICE LEVEL AGREEMENTS (SLAs) WITH MINIMAL RESOURCES, AND ALLOWING COMMON POOLS OF RESOURCES TO BE USED ACROSS PLURAL CUSTOMERS ON A DEMAND BASIS

BACKGROUND OF THE INVENTION

Field of the Invention

The present invention relates generally to a world-wide network, and more particularly to sites of a plurality of Internet World Wide Web (WWW) sites of various owners hosted by a service provider using a group of servers and meeting with agreed-upon service levels.

Description of the Related Art

The Internet is the world's largest network, and it has become essential to businesses as well as to consumers. Many businesses have started out-sourcing their e-business and e-commerce Web sites to service providers, instead of operating their Web sites on their own server(s) and managing them by themselves. Such a service provider must install a collection of servers in a farm called a "Web Server Farm (WSF)", or a "Universal Server Farm (USF)" which can be used by many different businesses to run their e-commerce and e-business applications.

These business customers (e.g., the service provider's "customers") have different "server resource" requirements for their Web sites and applications.

When businesses (hereafter referred to as "customers" or "customers of a server farm") out-source their e-commerce and/or e-business to a service provider, they must obtain some guarantee on the services they are getting (and will continue to obtain) from the service provider for their sites. Once the service provider has made a commitment to a customer to provide a certain "level" of service (e.g., referred to as a "Service Level Agreement (SLA)"), the provider must guarantee that level of service to that customer.

Figure 1 illustrates an abstracted view of a conventional server farm. A server farm 103 includes multiple servers which host customer applications, and is connected to Internet 101 via communications link(s) 102. Each customer's server resource requirements changes since the demands to customers' applications change continuously on a dynamic basis during each day of operations.

However, a problem with the conventional system and method used thereby is that, hitherto the present invention, there has been no provision for dynamically equipping the server farm such that server(s) and their resources can be dynamically allocated. Hence, there has been no flexibility in dynamically allocating servers and their resources to customers as the customer's demands change. This results in system-wide inefficiency and general dissatisfaction by the customer.

Another problem with the conventional system is that there are no Service Level Agreements (SLAs) based on dynamic allocation and de-allocation of servers to customer's server clusters.

Yet another problem with the conventional system is that there is no provisioning of SLAs in support of both a guaranteed number of servers and optional additional servers based on

the workload changes to customers' applications. Yet another problem with the conventional system is that a "hacker" or "hackers" can generate a large amount of workload to a customer's sites or to the server farm itself to "crash" servers or server farm.

SUMMARY OF THE INVENTION

In view of the foregoing and other problems of the conventional methods and structures, an object of the present invention is to provide a method and structure in which an allocation of server resources for a plurality of customers is dynamically controlled.

Another object of the present invention is to support the (minimum, maximum) server resource-based service level agreements for a plurality of customers.

Yet another object of the present invention is to control the allocation of additional server resources to a plurality of customers using the bounds on given service level metrics.

Still another object of the present invention is to support various service level metrics.

A further object of the present invention is to support the use of different metrics for different customers.

Another object of the present invention is to use a service level metric, the amount of allocated resources, and the inbound traffic rate, for defining the state of the current service level (M,N,R) for each customer.

Another object of the present invention is to use a "target" service level metric Mt to keep the actual service level M close to the target service level.

A further object of the present invention is to compute a "target" amount of resources Nt and the inbound traffic rate Rt from a given Mt and (M,N,R).

Still another object of the present invention is to provide and use formulas for computing Nt and Rt from Mt and (M,N,R).

A still further object of the present invention is to allow the use of numerical analysis or quick simulation techniques for deriving Nt and Rt in place of using formulas invented and described in this patent application.

Yet another object of the present invention is to support resource utilization U for M, average response time T for an actual service level M, and the response time percentile T% for the actual service level M (and therefore, the support of targets Ut, Tt and Tt%).

Another object of the present invention is to provide a method (decision algorithm) for deciding whether or not to add additional server resource(s) or to reduce ("throttle down") the inbound traffic to meet the service level agreements for a plurality of customers.

In a first aspect of the present invention, a method (and system) for managing and controlling allocation and de-allocation of resources based on a guaranteed amount of resource and additional resources based on a best effort for a plurality of customers, includes dynamically allocating server resources for a plurality of customers, such that the resources received by a customer are dynamically controlled and the customer receives a minimum (e.g., a minimum that is guaranteed) amount of resources as specified under a service level agreement (SLA).

In another aspect, a program storage device is provided for storing the program of the inventive method.

With the unique and unobvious features of the present invention, a server farm is equipped with a means to dynamically allocate servers (or server resources) to customers as demands change.

It is noted that a general service level agreement (SLA) on a server resource for a customer can be denoted by (Smin#(i), Smax#(i), Mbounds(i)), where Smin#(i) denotes the guaranteed minimum amount of server resources (e.g., the number of servers), Smax(i) denotes the upper bound on the amount of server resources that a customer may want to obtain when free resources are available, and Mbounds(i) gives two bounds: Mhighbound(i) and Mlowbound(i) on a service level metric M that is used in controlling the allocation of resources beyond the minimum for each i-th customer. Mhighbound(i) is used to decide when to add additional server resources and Mlowbound (i) is used to decide when to remove some server resources.

The minimum (or min) amount of server resources (e.g., number of servers) Smin#(i) is a guaranteed amount of server resources that the i-th customer will receive regardless of the server resource usage. The maximum (or max) amount of server resources Smax#(i) is the upper bound on the amount of server resources that the i-th customer may receive beyond the minimum provided that some unused server resources are available for allocation.

Therefore, the range between Smin#(i) and Smax#(i) represents server resources that are provided on an "as-available" or "best-effort" basis, and it is not necessarily guaranteed that the customer will obtain these resources at any one time, if at all. The allocation of additional resource(s) is performed so as to keep the performance metric within Mbounds(i).

Examples of Mbounds(i) include: (1) the bound on the server resource utilization that is denoted by Ubounds(i); (2) the bound on the average server response time that is denoted by Tbounds(i); and (3) the bound on the server response time percentile that is denoted by T%bounds(i).

Table 1 provides definitions and notations used throughout the present application. For example, when Mbounds(i) = Ubounds(i) = (Ulowbound(i),Uhighbound(i) = (50%, 80%), the

server farm tries to allocate additional server resources (or de-allocate some servers) to the i-th customer's server complex to keep the server resource utilization between 50% and 80%.

That is, when the server resource utilization goes above 80%, the server farm tries to keep the utilization below 80% by allocating additional server resources to the i-th customer when free resources are available. If free resources are not available, the server farm may need to limit the amount of incoming traffic to the i-th customer's server complex. Conversely, when the server resource utilization goes below 50%, the server farm tries to remove some server resources from the i-th customer in order to keep the utilization above 50%. In order to keep the observed metric M within the given Mbounds, the notion of a "target" metric Mt is introduced. Mt is a value that falls between Mlowbound and Mhighbound and the system of the present invention tries to keep the observed metric M as close as possible to the target metric Mt by adjusting server resources. In general, the unit cost of the server resources above the minimum guarantee is more than or equal to that of the server resources below the minimum.

Thus, the present invention provides a dynamic resource allocation to a plurality of customers to meet with the (min, max) server resources and performance metric based service level agreements. Unused (un-allocated) server resources are pooled and allocated and de-allocated from the pool, thus providing sharing of server resources among plurality of customer, leading to efficient use of server resources. Since incoming workload is regulated when it has exceeded server resources allocated, the system provides a "denial of services" to some workloads, thus preventing a crash of hosted customer sites and preventing a crash of the server farm itself.

BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing and other purposes, aspects and advantages will be better understood from the following detailed description of a preferred embodiment of the invention with reference to the drawings, in which:

Figure 1 illustrates an abstracted view of a conventional server farm;

Figure 2 illustrates a general overview of the operation and structure of the present invention;

Figure 3 illustrates a concept of a Service Level Agreement (Smin#, Smax#, Mbounds);

Figure 4 illustrates a graph showing the relationship of Metric M to the number of server resources, to show a concept of the present invention;

Figure 5 illustrates an overall system 500 and environment of the present invention; and

Figure 6 illustrates a decision method 600 for server allocation.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS OF THE INVENTION

Referring now to the drawings, and more particularly to Figures 1-6, there is shown a preferred embodiment of the method and structure according to the present invention.

PREFERRED EMBODIMENT

Referring to Figure 2, prior to describing the details of the invention, an overview and a primary object of the present invention will be described below.

As shown in Figure 2, the invention first monitors the inbound traffic rate R(i) 206, the currently assigned amount of server resources N(i) 205, and the current service level metric M(i) 204 for all customers 201 and 202.

Then, the inventive system performs the following actions only when M(i) falls outside of Mbounds(i), namely either M(i) is above Mhighbound(i) or M(i) is below Mlowbound(i), to avoid "allocation/de-allocation swings".

The "target" amount of server resources Nt(i), without changing the inbound traffic R(i), is computed. Further, the "target" inbound traffic rate Rt(i), without changing the allocated resource N(i), is computed in order to bring the service level metric M(i) close to the "targeted" service level metric Mt(i) from monitored R(i), N(i) and M(i) for all i. The target service level metric Mt(i) is the service level metric at or near which one wants to keep M(i) so that M(i) falls within Mbounds(i) = (Mlowbound(i),Mhighbound(i)).

Once Nt(i) and Rt(i) are computed, then it is decided how to move current M(i) to the target Mt(i), by either changing N(i) to Nt(i) (e.g., this involves either allocating server resources from free resource pool 203 to a customer's server set 201 or 202, or taking some server resources away from customer 201 or 202 and return to the pool 203) or by bounding the inbound traffic rate R(i) to Rt(i) (e.g., this is performed when either the maximum amount of resources has been already allocated or no free resource is available so that the only way to bring M(i) to Mt(i) is to reduce the amount of inbound traffic).

Once the decision has been made, it will then send a request to an appropriate systems resource manager (e.g., a "resource allocation manager" or an "inbound traffic controller").

Figure 3 illustrates the concept of the service level agreement (SLA) that the present invention supports for a plurality of customers. The service level agreement for each customer has the form of (Smin#, Smax#, Mbounds), where Smin# is the guaranteed amount of server resources (e.g., the number of servers), Smax# is the upper bound on the total amount of server resources that a customer may obtain when free resources are available, and Mbounds is a pair of bounds on the service level metric that are used in determining when to add additional resources or to remove some resources away. For ease of illustration, in Figure 3, the server resource is assumed to have (reside in) a single dimension. However, this could be a vector.

Figure 3 shows six operation spaces: A 301, B 302, C 303, D 304, E 305 and F 306. Because of the bounds Smin# 314, and Smax# 313, the feasible operation spaces are B 302 and E 305.

It is noted that the operation space D 304 could be made available especially when a server farm operator could "borrow" some servers from some customers when the customers are not fully utilizing their resources.

The operation space B 302 is a "non-desirable" space since the service level metric M is exceeding the bound Mhighbound 311. The operation space E 305 is the space in which the operational state should be kept. Furthermore, the upper portion of the space E 305 that is bounded by Mlowbound 312 and Mhighbound 311 is the operation space allowed by the exemplary service level agreement (SLA) that the present invention supports. It is noted that the metric M may be utilization, average response time, percentile response time, etc. Mbounds 307 may be Ubounds, Tbounds, T%bounds, etc. as suitably determined by the designer given constraints and requirements imposed thereon.

Figure 4 illustrates a primary concept of the present invention. Here, the operation space 305 is divided into two regions. A first region is called a "green belt" 405 (e.g., the region

bounded by Mlowbound 312 and Mhighbound 311), and a second region is the remaining space of the space 305.

In the present invention, the operation state which falls into the green belt 405 is deemed to be acceptable while the operation which falls outside of the green belt (e.g., below the green belt), is not acceptable since too many unnecessary resources are allocated, thereby incurring extra (wasteful) costs to a customer.

Figure 4 illustrates the target service level metric Mt 401 with respect to the service level metric bound Mbounds 307 and the green belt 405. Mt 401 is the target value that falls within the green belt 405. The upper bound on the green belt 405 is Mhighbound 311 and the lower bound is Mlowbound 312. The green belt 405 is also bounded by Smin# 314 and Smax# 313. Thus, the green belt 405 is a representation of an SLA of the form (Smin#, Smax#, Mbounds).

An object of the dynamic resource allocation according to the present invention is to keep the operation state within the green belt 405. When the current operation state that is denoted by (M,N,R) is at 403 in the space 305, the primary operation is to reduce the currently allocated amount of resources N to the target amount Nt, so that the service level metric M at 403 would move to the target metric Mt at 404.

When the current operation state that is denoted by (M,N,R) is at 402 in the space 302, the current resource N may be increased to Nt when some free resources are available for allocation, or the inbound traffic R may be reduced to Rt so that metric M at 402 would move to Mt at 404. When the current state is within the green belt 405, no action is taken. The green belt 405 therefore defines the allowable system operation state region such that any state within the green belt 405 meets the service level agreement (SLA).

Figure 5 illustrates an overall system 500 according to the present invention including a main system 501, an inbound traffic controller 506, and a server resource manager 509.

The main system 501 includes a decision module and methodology 503 (e.g., algorithm), a module 502 (algorithm) for computing targets Nt(i) and Rt(i), and a repository for storing Service Level Agreements (SLA) 504.

The module 502 computes the target values Nt(i) and Rt(i) from the monitored data M(i) 204, N(i) 205 and R(i) 206 for every customer whenever its operation state (M(i),N(i),R(i)) falls outside of the green belt 405 associated with the customer.

Then the decision module 503, using the SLA information, (M(i),N(i),R(i)), Nt(i) and Rt(i), decides what action to take.

That is, the decision module 503 decides either to change the current resource amount from N(i) to Nt(i) 508, or bound the current inbound traffic rate R(i) by Rt(i) 505, and then take appropriate action.

System 501 has a communications means to instruct "server resource manager" 509 to change resource allocation 510. The system 501 has a communications means to instruct "inbound traffic controller" 506 to bound the incoming traffic 507 to a specific customer site (201 or 202).

Tables 2 through 5 give various means in computing or deriving target values Nt(i) and Rt(i) for every customer i.

For example, Table 2 describes formulas for computing these targets when the service level metric M is the resource utilization U.

Table 3 describes a formula for computing these targets when the service level metric M is the average response time T. Here, the average response time was derived from the "M/M/m" multi-server queuing model.

It is noted that since the computation is used for the "hill climbing" optimization and is repeated periodically, and the amount of resources allocated or de-allocated at each step is

assumed to be very small compared to the amount of resources currently allocated, the use of "M/M/m" model should be quite acceptable even though the arrival rate might be different from Poisson and the job processing time may not be exponentially distributed. A major advantage of "M/M/m" model is that it offers the closed form formula as shown in Table 3.

Table 4 describes formulas for computing these targets when the service level metric M is the response time percentile T%. Again, the "M/M/m" queuing model is assumed in computing the targets.

Table 5 shows that, instead of using a formula to compute the targets (Nt,Rt), one could use any numerical computation tool or quick simulation tool.

Figure 6 describes the decision method 600 employed by module (algorithm) 503 for server resource allocation in the system 501.

The decision method 600 looks for (e.g., attempts to obtain) potential revenue maximization opportunity when allocating free resources to various customers. It first seeks any opportunity to de-allocate resources, next allocates additional resources to customers whose service level metric is outside of the green belt 405 (Figure 4) and finally looks for when the customer's inbound traffic must be throttled (reduced) due to exhaustion of free resources or the maximum amount of resources has been already allocated.

Method 600 begins at step 601. In step 602, the target values (Nt(i),Rt(i)) are computed for every i. Further, the variable "ITC-informed(i)" = "no" is set for all "i". This variable keeps a record of whether or not throttling on inbound traffic has been applied or not prior to the current computation. This computation or examination is performed periodically to check whether or not any service level agreements have been violated, that is, checking whether or not any operation states falls outside of green belts. An examination is conducted in a time interval called a cycle-time. A cycle-time is a system operation configuration parameter. For example, a cycle

time value could be selected from a value between 1 second to 60 seconds. Whether to choose a smaller value or a larger value depends on how fast one can adjust resource allocation/de-allocation.

In step 603, it is determined whether or not the service cycle time has expired. If it has expired (e.g., a "YES" in step 603), the process loops back to step 602.

If "NO" in step 603, then in step 604 it is checked whether the operation state M(i) is within the green belt 405 (e.g., see Figure 4).

If so (e.g., a "YES"), then step 605 is executed in which the system waits for the cycle time to elapse and the process loops back to step 602.

If "NO" in step 604, then in step 606, it is checked whether any customer exists such that the target resource amount Nt(i) is less than the current amount N(i) (i.e., seeking an opportunity to de-allocate server resources from customers and placing them back into the pool of "free" resources).

If "YES" in step 606, one possibility that Nt(i) is less than N(i) is that because the inbound traffic has been throttled. This condition is tested at step 607. Step 606 identifies all those customers such that Nt(i) is less than N(i). Step 607 is applied to only those customers identified in step 606. Step 607 checks if there is any customer whose inbound traffic is currently throttled. If step 607 is "YES", step 609 is executed. Step 609 issues a command to ITC 506 to stop applying the throttling on the i-th customer's inboud traffic. and sets ITC-informed (i) = "no".

When Nt(i) is less than N(i) ("YES" in step 606) and the inbound traffic is not throttled ("NO" in step 607), that means that too many resources have been allocated to the given amount of inbound traffic for the i-th customer traffic, step 608 seeks to de-allocate resources away from the i-th customer.

In step 610, it is checked whether the resource(s) must be increased for any customer identified in step 606. There is no action required for those customers whose target value Nt(i) is equal to the observed value N(i). Step 610 identifies a customer whose server resource must be increased.

If so ("YES" in step 610) and if free resources are available ("YES" in step 611), then step 612 is executed to allocate additional resources (e.g., allocate up to Nt(i) - N(i) resources without exceeding Smax#(i)).

When additional resources must be allocated, and yet no free resource is available (e.g., a "NO" in step 611), then it is necessary to "re-claim" resources from those customers who have more than the guaranteed minimum (e.g., N(j) > Smin#(j)) (step 614).

When additional resource(s) must be allocated ("YES" in step 610), and no free resource is available ("NO" in step 611) and if the currently allocated resource N(i) is more than or equal to the guaranteed minimum Smin#(i) ("NO" in step 613), then the inbound traffic must be throttled (step 615). That is, the inbound traffic controller 506 is instructed to bound the traffic by Rt(i), and ITC-informed(i) is set to "YES".

As described above, with the unique and unobvious features of the present invention, a dynamic resource allocation is provided to a plurality of customers to meet with the (min,max) server resources and performance metric-based service level agreements.

When describing the embodiment of this invention, often a fixed size unit of allocable or de-allocable resources were assumed. However, one can easily generalize to the case where each allocable unit has a different amount.

Further, it is noted that the method of the invention may be stored on a storage medium as a series of program steps, and can be executed by a digital data processing apparatus.

While the invention has been described in terms of a preferred embodiment, the invention is not limited thereto and those skilled in the art will recognize that the invention can be practiced with modification within the spirit and scope of the appended claims.

CLAIMS

What is claimed is:

1. A method for managing and controlling allocation and de-allocation of resources based on a guaranteed amount of resource and additional resources based on a best effort for a plurality of customers, said method comprising:

dynamically allocating server resources for a plurality of customers, such that said resources received by a customer are dynamically controlled and said customer receives a guaranteed minimum amount of resources as specified under a service level agreement (SLA).

2. The method according to claim 1, further comprising:

utilizing a performance metric to increase or decease an inbound traffic to a customer.

3. The method according to claim 1, further comprising:

supporting minimum and maximum server resource-based service level agreements for a plurality of customers.

4. The method according to claim 1, further comprising:

utilizing performance metrics to control the allocation of additional server resources to a plurality of customers using bounds on given service level metrics.

5. The method according to claim 1, further comprising:

supporting a plurality of service level metrics.

6. The method according to claim 1, further comprising:

selectively utilizing a plurality of different metrics for a plurality of different customers.

7. The method according to claim 1, further comprising:

utilizing a service level metric, an amount of allocable resources, and an inbound traffic rate, for defining a state of a current service level (M,N,R) for each customer.

8. The method according to claim 1, further comprising:

utilizing a target service level metric Mt to maintain an actual service level M substantially at or near a target service level so as to be guaranteed to fall between low and high bounds (Mlowbound and Mhighbound) specified in a service level agreement (SLA).

9. The method according to claim 1, further comprising:

computing a target amount of resources Nt and an inbound traffic rate Rt from a given target service level metric Mt and (M,N,R).

10. The method according to claim 1, further comprising:

performing at least one of a numerical analysis, a mathematical formulaic operation, an add-one/subtract-one, and a quick simulation for deriving a target amount of resources Nt and an inbound traffic rate Rt.

11. The method according to claim 1, further comprising:

supporting a resource utilization U for an actual service level M, average response time T for an actual service level M, and a response time percentile T% for an actual service level M, thereby to support targets of Ut, Tt and Tt%.

12. The method according to claim 1, further comprising:

deciding whether or not to add a server resource or to reduce an inbound traffic rate to meet service level agreements for a plurality of customers.

13. The method according to claim 1, further comprising:

providing a server farm including means for dynamically allocating servers or server resources to customers as demands of said customers change.

14. The method according to claim 1, further comprising:

designating a service level agreement (SLA) on a server resource for a customer as a form (Smin#(i), Smax#(i), Mbounds(i)), where Smin#(i) denotes a guaranteed minimum amount of server resources, Smax(i) denotes an upper bound on an amount of server resources that a customer desires to obtain when free resources are available, and Mbounds(i) that includes a low bound (Mlowbound(i)) and a high bound (Mhighbound(i)) designating bounds on a service level metric for allocating resources beyond the minimum amount Smin#(i) for each i- th customer.

15. The method according to claim 14, wherein a minimum amount of server resources Smin#(i) comprises a guaranteed amount of server resources that the i-th customer will receive regardless of the server resource usage, and

wherein a maximum amount of server resources Smax#(i) comprises the upper bound on the amount of server resources that the i-th customer may receive beyond the minimum amount provided that some unused server resources are available for allocation.

16. The method according to claim 15, wherein a range between Smin#(i) and Smax#(i) represents server resources that are provided on an as-available basis, such that the customer is not guaranteed to obtain these resources at any one time, if at all.

17. The method according to claim 1, wherein an allocation of an additional resource is performed so as to keep the performance metric within Mbounds(i).

18. The method according to claim 17, wherein said Mbounds(i) includes any one of bounds on the server resource utilization that are denoted by Ubounds(i), bounds on the average server response time that are denoted by Tbounds(i), and bounds on the server response time percentile that are denoted by T%bounds(i).

19. The method according to claim 1, further comprising:

when a server resource utilization goes above a predetermined set limit Mhighbound(i), attempting, by a server farm, to maintain the utilization between said predetermined set limits Mbounds(i) by allocating additional server resources to the i-th customer when free resources are available.

20. The method according to claim 19, further comprising:

if free resources are not available, then limiting, by the server farm, an amount of incoming traffic to the i-th customer's server.

21. The method according to claim 1, further comprising:

controlling said dynamic resource allocation to said plurality of customers to meet a value between the minimum and maximum server resources and performance metric-based service level agreements.

22. The method according to claim 1, further comprising:

monitoring an inbound traffic rate R(i), a currently assigned amount of server resources N(i), and a current service level metric M(i) for all of said plurality of customers.

23. The method according to claim 22, further comprising:

computing a target amount of server resources Nt(i), without changing an inbound traffic R(i).

24. The method according to claim 23, further comprising:

computing a target inbound traffic rate Rt(i), without changing an allocated resource N(i), to bring the service level metric M(i) to the targeted service level metric Mt(i) from monitored R(i), N(i) and M(i) for all i,

wherein the target service level metric Mt(i) comprises the service level metric substantially at or near where M(i) is to be maintained, and bounded by Mbounds(i).

25. The method according to claim 24, further comprising:

determining how to adjust a current M(i) to the target Mt(i), by one of changing N(i) to Nt(i) and by bounding the inbound traffic rate R(i) to Rt(i).

26. The method according to claim 25, further comprising:

requesting a system resource manager to perform the resource allocation.

27. The method according to claim 26, further comprising:

requesting an inbound traffic controller to throttle an amount of inbound traffic to the plurality of customers.

28. The method according to claim 1, further comprising:

maximizing revenue potential when allocating resources beyond a minimum amount for a customer.

29. The method according to claim 1, wherein a unit of said resources comprises a fixed size unit of allocable or de-allocable resources.

30. The method according to claim 1, wherein a unit of each allocable resource has a different amount.

31. A method of deciding server resource allocation for a plurality of customers, comprising:

computing target values (Nt(i),Rt(i)) for every customer i and setting a variable "ITC-informed(i)" = "no" for all customers "i" such that a record is kept of whether or not throttling on inbound traffic is being applied or not during a given service cycle time;

determining whether or not the service cycle time has expired;

if the service cycle time has not expired, then checking whether an operation state M(i) is within a predetermined area defined by a metric and a number of resources;

if the operation state is not within the predetermined area, then checking whether any customer exists such that a target resource amount Nt(i) is less than a current amount N(i);

if Nt(i) is less than N(i), then determining whether the inbound traffic has been throttled, and determining whether any "i" is ITC-informed(i); and

if the inbound traffic has been throttled, then removing the throttling by directing an inbound traffic controller to stop throttling i-th traffic class and setting ITC-informed (i) = "no".

32. The method according to claim 31, further comprising:

when Nt(i) is less than N(i) and it is determined that the inbound traffic is not throttled, deallocating resources from said customers.

33. The method according to claim 32, further comprising:

determining whether the resources must be increased by selecting any i and determining whether Nt(i) is greater than N(i).

34. The method according to claim 33, further comprising:

if it is determined that Nt(i) is greater than N(i) and if free resources are judged to be available, then allocating additional resources up to Nt(i) - N(i) resources without exceeding a maximum amount of server resources Smax#(i)).

35. The method according to claim 33, further comprising:

if it is determined that Nt(i) is greater than N(i) and if free resources are judged to be unavailable and if the currently allocated resource N(i) is less than the guaranteed minimum Smin#(i), then reclaiming resources from those customers j having more than a guaranteed minimum such that N(j) > Smin#(j).

36. The method according to claim 33, further comprising:

if it is determined that Nt(i) is greater than N(i) and if free resources are judged to be unavailable and if the currently allocated resource N(i) is more than or equal to the guaranteed minimum Smin#(i), then throttling the inbound traffic.

37. The method according to claim 36, further comprising:

bounding, by the inbound traffic controller, the traffic by Rt(i).

38. The method according to claim 31, further comprising:

searching for a potential revenue maximization opportunity when allocating free resources to various customers.

39. The method according to claim 38, further comprising:

first seeking to de-allocate resources, then allocating additional resources to customers whose service level metric is outside of a predetermined area, and thirdly searching for when the customer's inbound traffic must be throttled due to exhaustion of free resources or the maximum amount of resources has been already allocated.

40. A system for managing and controlling allocation and de-allocation of resources based on a guaranteed amount of resources and additional resources based on a best effort for a plurality of customers, said system comprising:

a plurality of servers; and

a resource allocation device for dynamically allocating server resources for a plurality of customers, such that said resources received by a customer are dynamically controlled and said customer receives a guaranteed minimum amount of resources as specified under a service level agreement (SLA).

41. A system for managing server resources for a plurality of customers, comprising:

a main system;

an inbound traffic controller operably coupled to said main system; and

a server resource manager coupled to said main system,

wherein said main system includes a decision module, a module for computing a target amount of resources Nt(i) and a target inbound traffic rate Rt(i), and a repository for storing Service Level Agreements,

wherein said decision module computes the target values Nt(i) and Rt(i) from monitored service level data M(i), N(i) and R(i) for every customer, such that a resource allocation is dynamically optimized for each customer.

42. The system according to claim 41, wherein an allocation and de-allocation of said resources is based on a guaranteed amount of resource and additional resources based on a best effort for the plurality of customers.

43. The system according to claim 41, wherein said resources are dynamically allocated for the plurality of customers, such that said resources received by a customer are dynamically controlled and said customer receives a guaranteed minimum amount of resources as specified under a service level agreement (SLA).

44. The system according to claim 41, wherein said decision module, based on the SLA information, (M(i),N(i),R(i)), Nt(i) and Rt(i), decides which action to take, to reallocate resources.

45. The system according to claim 44, wherein the decision module decides one of changing the current resource amount from N(i) to the target resource amount Nt(i), and bounding a current inbound traffic rate R(i) by Rt(i).

46. The system according to claim 45, wherein said main system instructs said server resource manager to change resource allocation and for instructing said inbound traffic controller to bound the incoming traffic to a specific customer site.

47. A program product device for storing a program for execution by a digital data processing apparatus to perform a method of managing and controlling allocation and de-allocation of resources based on a guaranteed amount of resource and additional resources based on a best effort for a plurality of customers, said method comprising:

dynamically allocating server resources for a plurality of customers, such that said resources received by a customer are dynamically controlled and said customer receives a guaranteed minimum amount of resources as specified under a service level agreement (SLA).

48. A program product device for storing a program for execution by a digital data processing apparatus to perform a method of deciding server resource allocation for a plurality of customers, comprising:

computing target values (Nt(i),Rt(i)) for every customer i and setting a variable "ITC-informed(i)" = "no" for all customers "i" such that a record is kept of whether or not throttling on inbound traffic is being applied or not during a given service cycle time;

determining whether or not the service cycle time has expired;

if the service cycle time has not expired, then checking whether an operation state M(i) is within a predetermined area defined by a metric and a number of resources;

if the operation state is not within the predetermined area, then checking whether any customer exists such that a target resource amount Nt(i) is less than a current amount N(i);

if Nt(i) is less than N(i), then determining whether the inbound traffic has been throttled, and determining whether any "i" is ITC-informed(i); and

if the inbound traffic has been throttled, then removing the throttling by directing an inbound traffic controller to stop throttling i-th traffic class and setting ITC-informed (i) = "no".

METHOD AND APPARATUS FOR DYNAMICALLY ADJUSTING RESOURCES ASSIGNED TO PLURALITY OF CUSTOMERS, FOR MEETING SERVICE LEVEL AGREEMENTS (SLAs) WITH MINIMAL RESOURCES, AND ALLOWING COMMON POOLS OF RESOURCES TO BE USED ACROSS PLURAL CUSTOMERS ON A DEMAND BASIS

ABSTRACT OF THE DISCLOSURE

A method (and system) for managing and controlling allocation and de-allocation of resources based on a guaranteed amount of resource and additional resources based on a best effort for a plurality of customers, includes dynamically allocating server resources for a plurality of customers, such that the resources received by a customer are dynamically controlled and the customer receives a guaranteed minimum amount of resources as specified under a service level agreement (SLA).

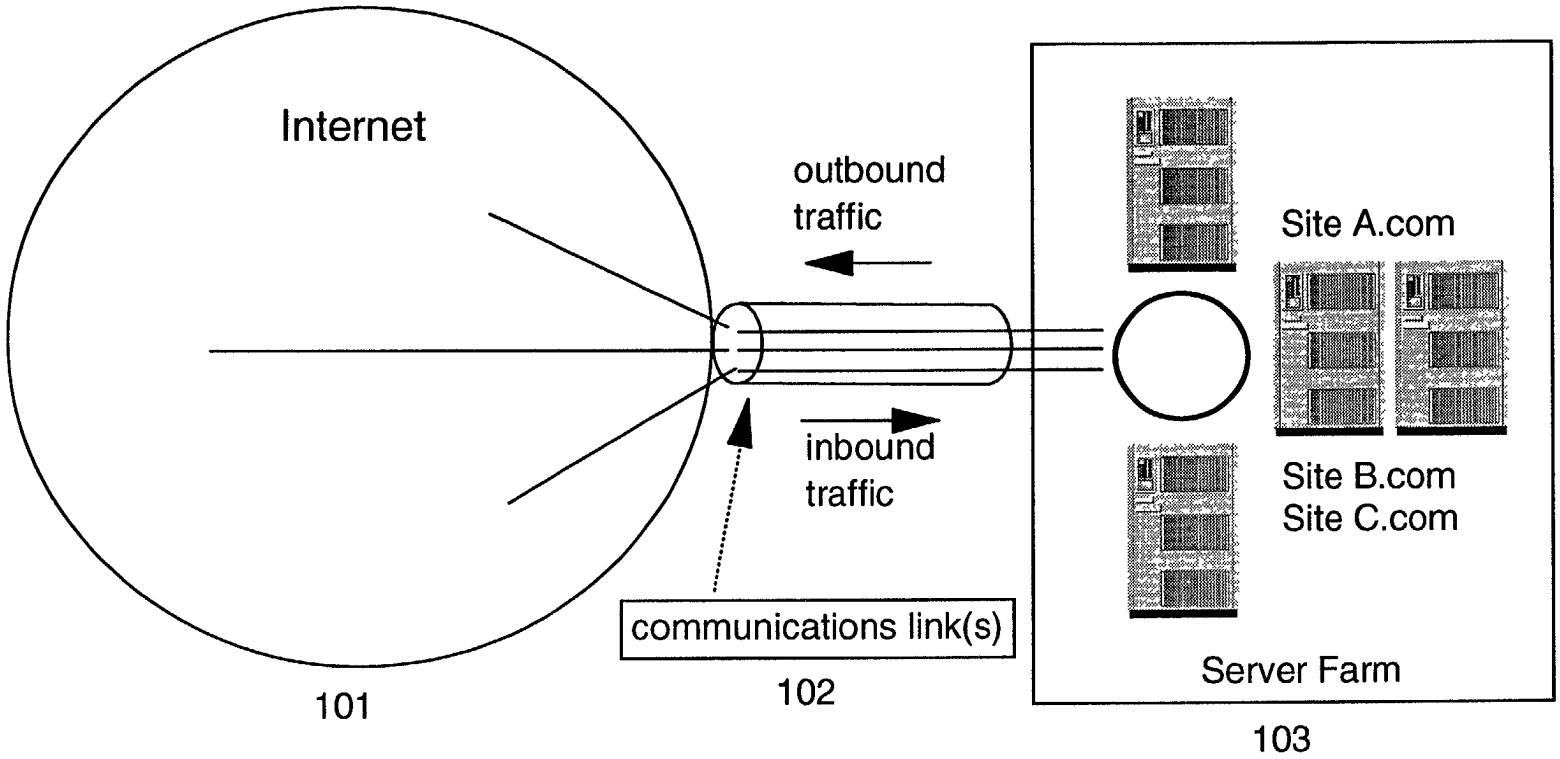
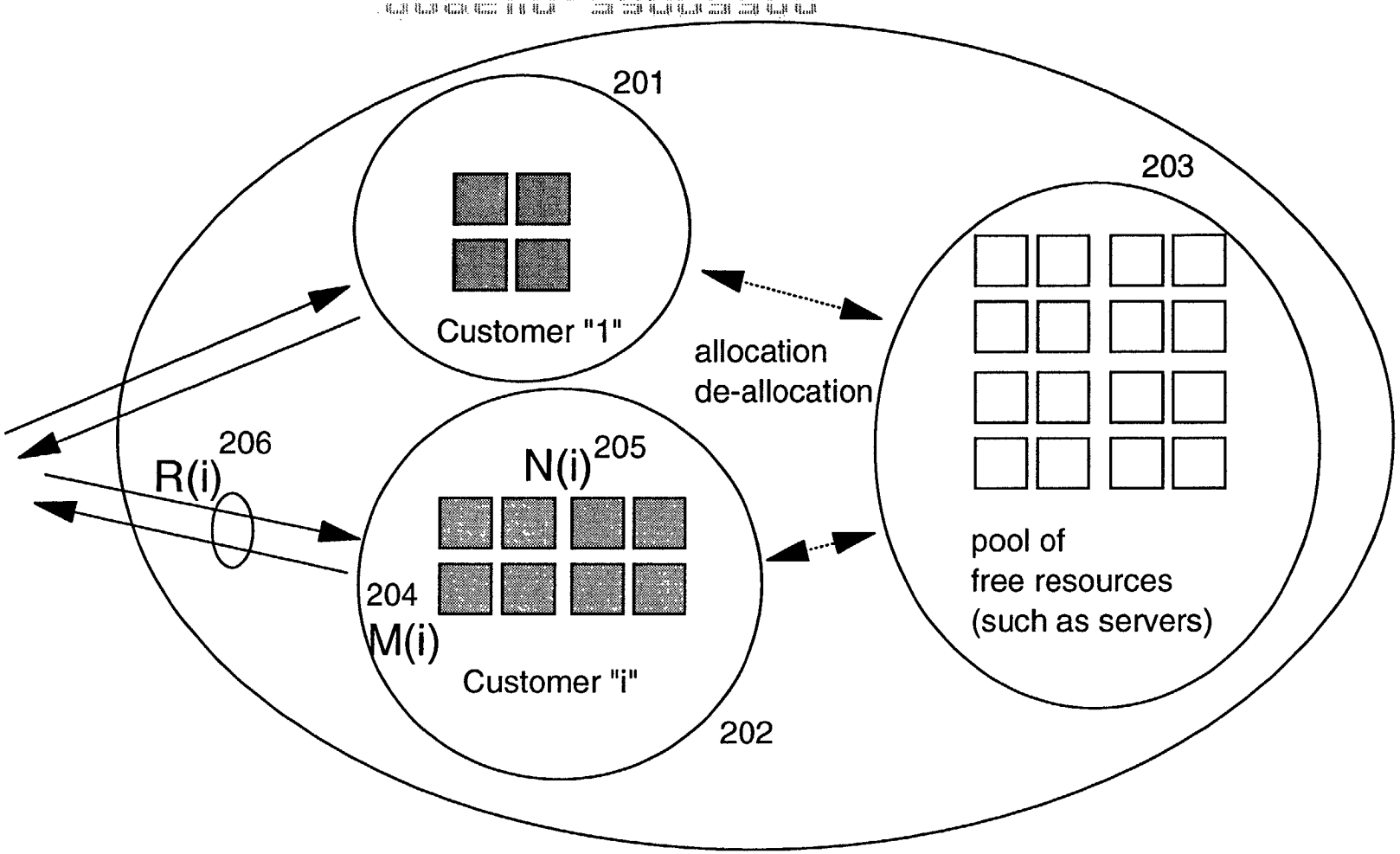

Internet
outbound
traffic
inbound
traffic
Site A.com
Site B.com
Site C.com
communications link(s)
Server Farm
101
102
103

Figure 1



Measure R(i), N(i), and M(i).
Compute Nt(i) and Rt(i) from Mt(i), R(i), N(i) and M(i),
and then if needed, move M(i) to Mt(i) by either changing N(i) to Nt(i) or changing R(i) to Rt(i).

Figure 2

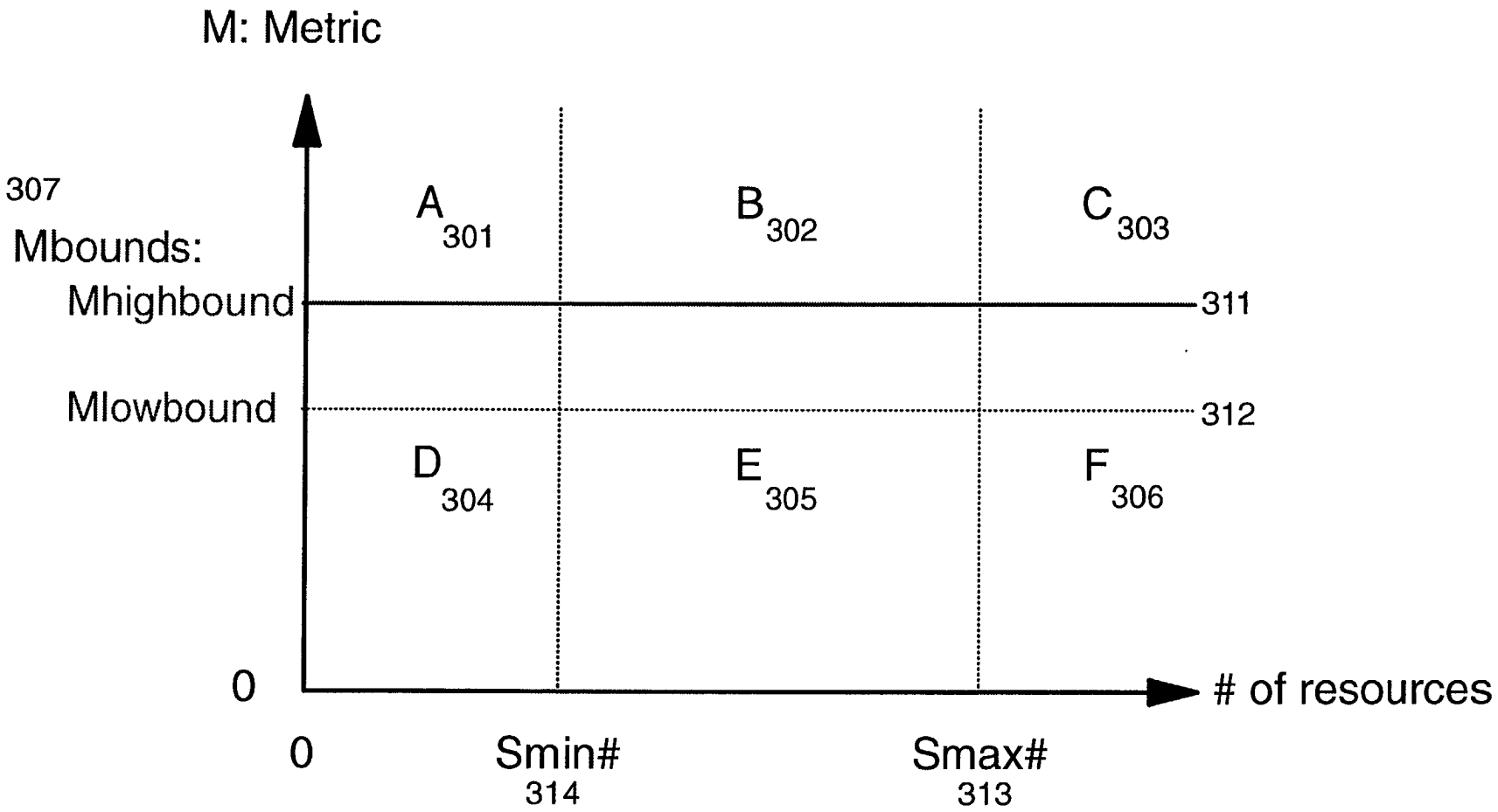

M: Metric
307
Mbounds:
Mhighbound
Mlowbound
A
301
B
302
C
303
311
312
D
304
E
305
F
306
0
0
Smin#
314
Smax#
313
# of resources

Figure 3

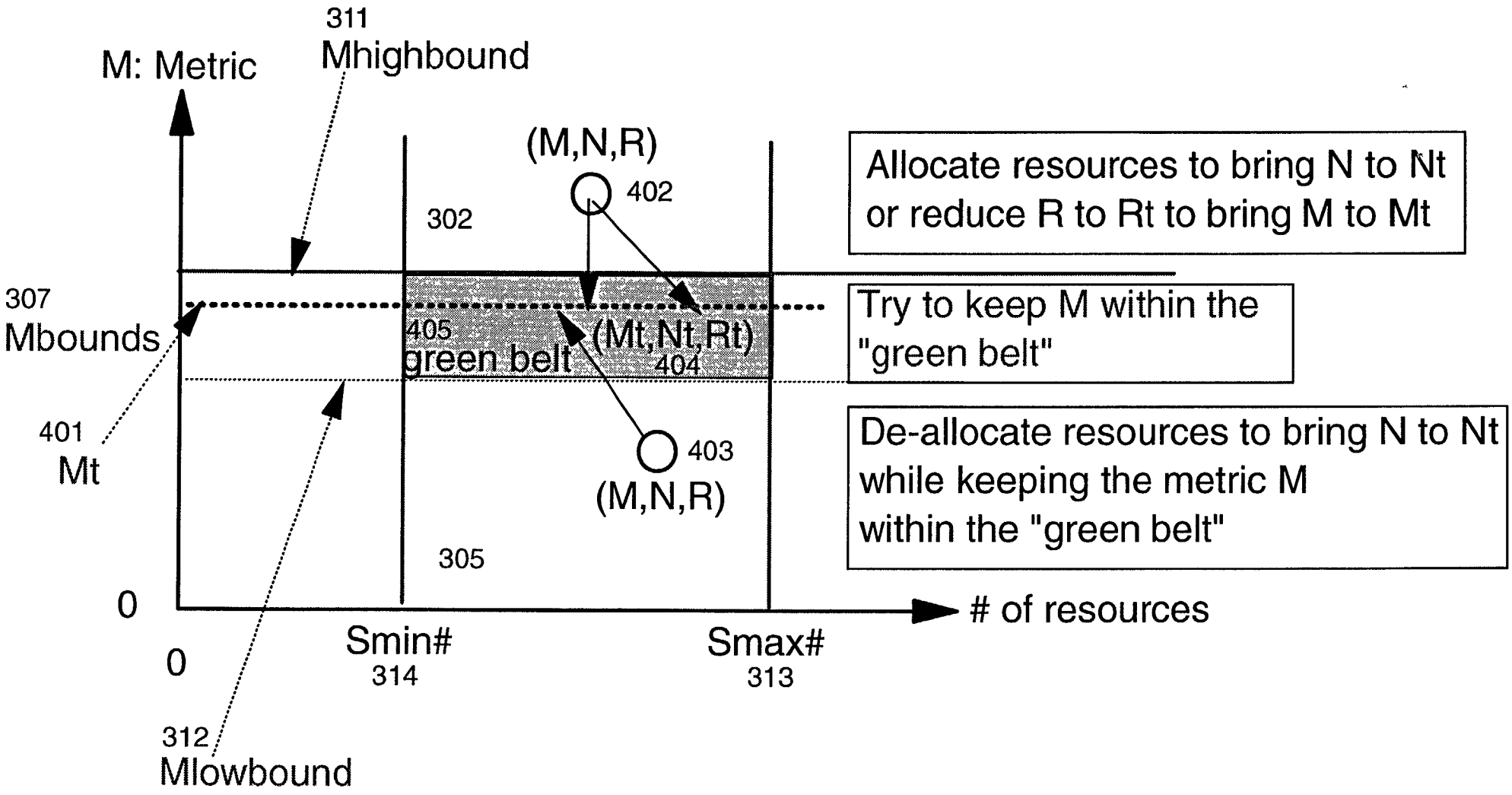

311
Mhighbound
M: Metric
(M,N,R)
402
302
Allocate resources to bring N to Nt
or reduce R to Rt to bring M to Mt
307
Mbounds
405
green belt
(Mt,Nt,Rt)
404
Try to keep M within the
"green belt"
401
Mt
403
(M,N,R)
De-allocate resources to bring N to Nt
while keeping the metric M
within the "green belt"
305
0
# of resources
0
Smin#
314
Smax#
313
312
Mlowbound

Figure 4

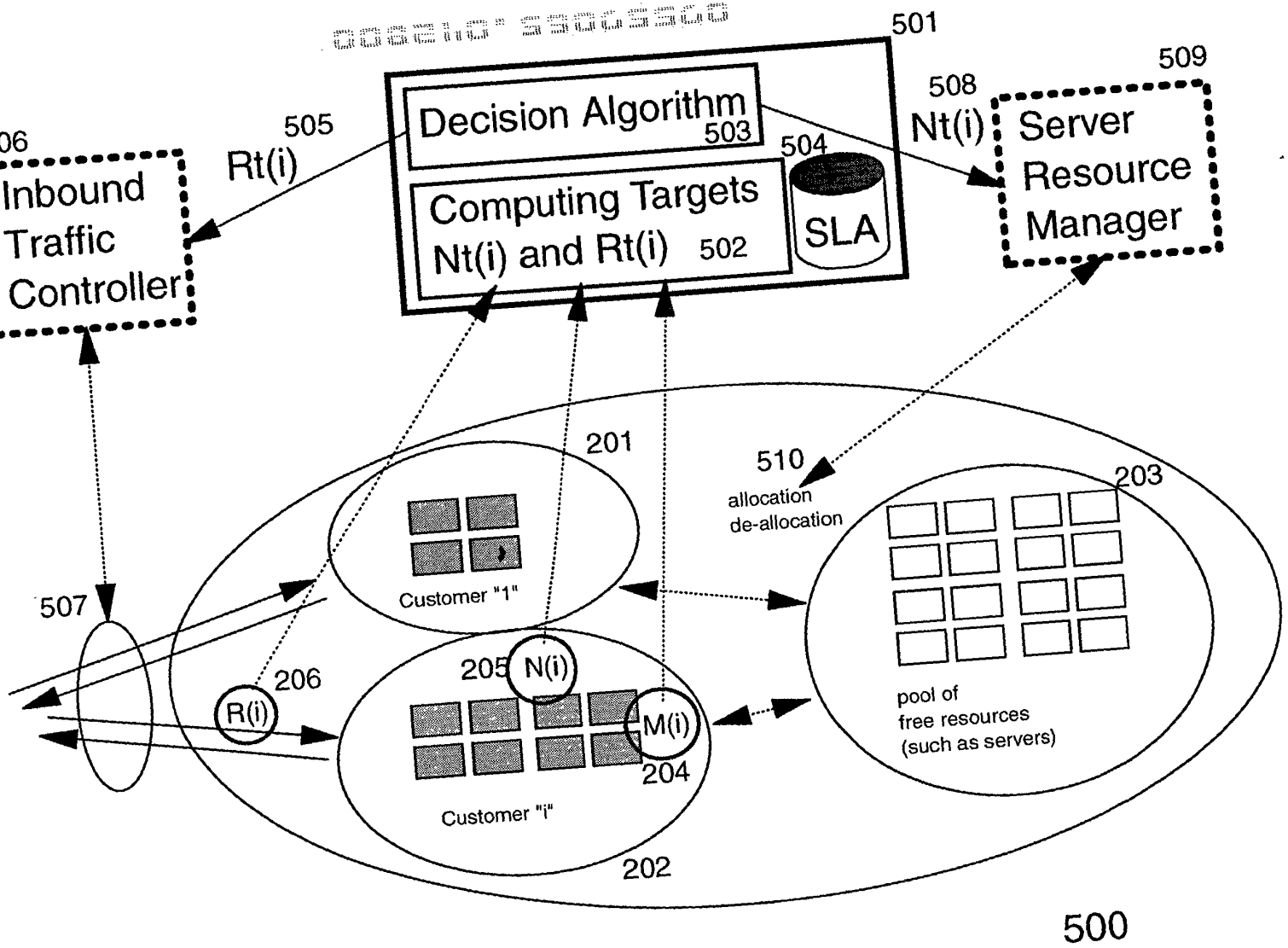

501
Decision Algorithm
503
Computing Targets
Nt(i) and Rt(i) 502
504
SLA
505
Rt(i)
506
Inbound
Traffic
Controller
508
Nt(i)
509
Server
Resource
Manager
510
allocation
de-allocation
201
Customer "1"
203
pool of
free resources
(such as servers)
507
206
R(i)
205
N(i)
M(i)
204
Customer "i"
202
500

Figure 5

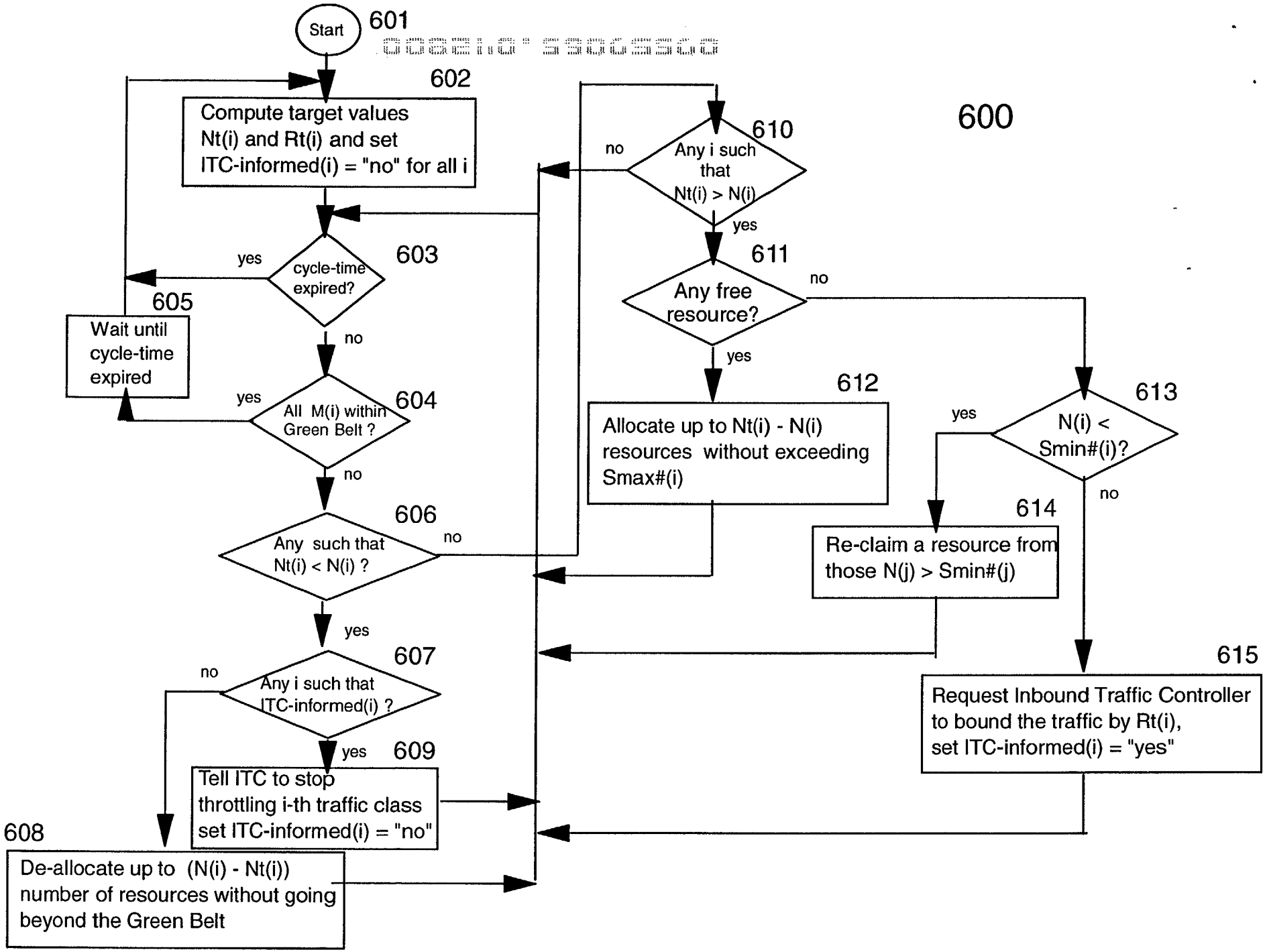

Start
601
602
Compute target values
Nt(i) and Rt(i) and set
ITC-informed(i) = "no" for all i
603
cycle-time
expired?
yes
605
Wait until
cycle-time
expired
no
604
All M(i) within
Green Belt ?
yes
no
606
Any such that
Nt(i) < N(i) ?
no
yes
607
Any i such that
ITC-informed(i) ?
no
yes
609
Tell ITC to stop
throttling i-th traffic class
set ITC-informed(i) = "no"
608
De-allocate up to (N(i) - Nt(i))
number of resources without going
beyond the Green Belt
610
Any i such
that
Nt(i) > N(i)
no
yes
611
Any free
resource?
yes
no
612
Allocate up to Nt(i) - N(i)
resources without exceeding
Smax#(i)
613
N(i) <
Smin#(i)?
yes
no
614
Re-claim a resource from
those N(j) > Smin#(j)
615
Request Inbound Traffic Controller
to bound the traffic by Rt(i),
set ITC-informed(i) = "yes"
600

Figure 6

Smin#(i) : the amount of resources guaranteed for the i-th customer. This can be a vector.

Smax#(i) : the maximum amount of service resources that could be made available to the i-th customer. This can be a vector.

Mbounds(i) : the bounds on the service level metric.
Each "bounds" consists of a pair, "highbound" and "lowbound".

- **Ubounds(i)** : the bound on the utilization of resources allocated to the i-th customer
- **Tbounds(i)** : the bound on the agreed upon average server response time for the i-th customer
- **T%bounds(i)** : the bound on the agreed upon server response time percentile for the i-th customer

(Smin#(i),Smax#(i),Mbound(i)) : the SLA supported by the invention

N(i) : the number (or amount of) of resources currently allocated to the i-th customer. this could be a vector.

R(i) : the current inbound traffic rate for the i-th customer. This could be a vector when more than one type of traffic is defined for each customer.

M(i) : the current value of the metric M for the i-th customer. This could be a vector. Examples are:

- **U(i)** : the current utilization of the allocated resources to the i-th customer
- **T(i)** : currently observed server response time average for the i-th customer
- **T%(i)** : currently observed server response time percentile for the i-th customer

Mt(i) : the "target" (want to achieve) metric value for the i-th customer. Its dimension is same as the dimension of M(i).
This is within the defined "green belt" which is the region within which M(i) is kept.
Examples of Mt(i) are:

- **Ut(i)** : the target resource utilization when M = U,
- **Tt(i)** : the target average response time when M = T
- **Tt%(i)** : the target percentile response time when M = T%

Table 1

For Utilization as Metric: M = U and Mt = Ut

The following relationships hold among various variables:
U(i) = C(i)R(i) / N(i), where C(i) is a constant
Ut(i) = C(i)R(i) / Nt(i), and
Ut(i) = C(i)Rt(i) / N(i).

From the above and from the given values of N(i), R(i), U(i), and the target value Ut(i), Nt(i) and Rt(i) can be computed as follow:
Nt(i) = CEILING [N(i)U(i) / Ut(i)],and
Rt(i) = FLOOR [R(i)Ut(i) / U(i)],
where CEILING gives the smallest interger exceeding and
FLOOR gives the largest integer not exceeding.

Table 2

For Average Response Time as Metric: M = T and Mt = Tt

S(i) : server "service" (or procesing) time for the i-th customer, this can be computed from observing each individual server service time, or estimated from a queueing formula:

S(i) is a function of {T(i),R(i),N(i)}

If the cluster of servers is modeled by the M/M/m queueing system,

S(i) = ((R(i)T(i)+N(i)+p{N(i)}) - SQRT((R(i)T(i)+N(i)+p{N(i)})**2 - 4R(i)T(i)R(i))) / 2R(i)

where p{m} is the probability that there are m requests in the i-th customer's server cluster

For the M/M/m queueing model,

Tt(i) ~ S(i) + p{Nt(i)}S(i) / (Nt(i)-R(i)S(i))

Tt(i) ~ S(i) + p{N(i)}S(i) / (N(i)-Rt(i)S(i))

Therefore,

Nt(i) = CEILING [R(i)S(i) + p{Nt(i)}S(i) / (Tt(i)-S(i))]

Rt(i) = FLOOR [N(i)/S(i) - p{N(i)}/(Tt(i)-S(i))]

where p{m} is the probability that there are m requests in the customer's server cluster

Table 3

For Percentile Response Time as Metric: M = T% and Mt = Tt%

If T%(i) > T%bound(i), then the average response time T(i) needs to be reduced by (T%(i) - T(i)). Therefore, for T%(i) to approach T%bound, the average response time target Tt(i) becomes:

$$Tt(i) = T(i) - (T\%(i) - T\%bound(i)).$$

For the M/M/m queueing model,

$$Tt(i) \sim S(i) + p\{Nt(i)\}S(i) / (Nt(i)-R(i)S(i))$$

$$Tt(i) \sim S(i) + p\{N(i)\}S(i) / (N(i)-Rt(i)S(i))$$

and thus,

$$\mathbf{Nt(i)} = \text{CEILING } [R(i)S(i) + p\{Nt(i)\}S(i) / (Tt(i)-S(i))]$$

$$\mathbf{Rt(i)} = \text{FLOOR } [N(i)/S(i) - (p\{N(i)\}/(Tt(i)-S(i))]$$

where p{m} is the probability that there are m requests in the customer's server cluster

Table 4

For any given metric M,

There are quick simulation tools, quick numerical computation tools and other approximation formura are available in computing **Nt(i)** and **Rt(i)** from given (i.e., measured) values of R(i), N(i) and M(i).

Table 5

DECLARATION AND POWER OF ATTORNEY

As a below named inventor, I hereby declare that:

My residence, post office address and citizenship are as stated below next to my name; I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled: METHOD AND APPARATUS FOR DYNAMICALLY ADJUSTING RESOURCES ASSIGNED TO PLURALITY OF CUSTOMERS, FOR MEETING SERVICE LEVEL AGREEMENTS (SLAs) WITH MINIMAL RESOURCES, AND ALLOWING COMMON POOLS OF RESOURCES TO BE USED ACROSS PLURAL CUSTOMERS ON A DEMAND BASIS

the specification of which:
(check one)

☒ is attached hereto.
☐ was filed on _____, as Application Serial No. _____ and was amended on _____.

I hereby state that I have reviewed and understand the contents of the above identified specification, including the claims, as amended by any amendment referred to above.

I acknowledge the duty to disclose information which is material to the patentability of this application in accordance with Title 37, Code of Federal Regulations, § 1.56.

I hereby claim foreign priority benefits under Title 35, United States Code, § 119 of any foreign application(s) for patent or inventor's certificate listed below and have also identified below any foreign application for patent or inventor's certificate having a filing date before that of the application on which priority is claimed:

Prior Foreign Application(s):

Number	Country	Day/Month/Year	Priority Claimed

I hereby claim the benefit under Title 35, United States Code, § 120 of any United States application(s) listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States application in the manner provided by the first paragraph of Title 35, United States Code, § 112, I acknowledge the duty to disclose material information as defined in Title 37, Code of Federal Regulations, § 1.56 which occurred between the filing date of the prior application and the national or PCT international filing date of this application:

Prior U.S. Applications:

Serial No.	Filing Date	Status

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

As a named inventor, I hereby appoint the following attorneys and/or agents to prosecute this application and transact all business in the Patent and Trademark Office connected therewith: We hereby appoint Manny Schecter, Registration No.31,722, Terry J. Ilardi, Registration No. 29,936, Christopher A. Hughes, Registration No. 26,914, Edward A. Pennington, Registration No. 32,588, John E. Hoel, Registration No. 26,279, Joseph C. Redmond, Jr., Registration No. 18,753, Douglas W. Cameron, Registration No. 31,596, Louis P. Herzberg, Registration No. 41,500, Kevin M. Jordan, Registration No.40,277, Stephen C. Kaufman, Registration No.29,551, Daniel P. Morris, Registration No.32,053, Louis J. Percello, Registration No.33,206, Jay P. Sbrollini, Registration No. 36,266, David M. Shofi, Registration No. 39,835, Paul J. Otterstedt, Registration No. 37,411 and Robert M. Trepp, Registration No. 25,933, to prosecute this application and transact all business in the United States Patent and Trademark Office connected therewith.

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